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(54) **ULTRABARRIER SUBSTRATES**

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(52) **U.S. Cl.** **428/446**; 428/457; 428/469; 428/688; 428/500; 428/411.1; 428/690; 426/126

(58) **Field of Search** 428/411.1, 457, 428/469, 688, 446, 500, 690; 426/126

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,475,307	A	10/1969	Knox et al.
3,607,365	A	9/1971	Lindlof
4,098,965	A	7/1978	Kinsman
4,283,482	A	8/1981	Hattori et al.
4,581,337	A	4/1986	Frey et al.
4,624,867	A	11/1986	Iijima et al.
4,695,618	A	9/1987	Mowrer
4,842,893	A	6/1989	Yializis et al.
4,954,371	A	9/1990	Yializis
5,032,461	A	7/1991	Shaw et al.
5,036,249	A	7/1991	Pike-Biegunski et al.
5,124,204	A	6/1992	Yamashita et al.
5,189,405	A	2/1993	Yamashita et al.
5,237,439	A	8/1993	Misono et al.
5,260,095	A	11/1993	Affinito
5,354,497	A	10/1994	Fukuchi et al.
5,395,644	A	3/1995	Affinito
5,427,638	A	6/1995	Goetz et al.
5,440,446	A	8/1995	Shaw et al.
5,536,323	A	7/1996	Kirlin et al.
5,547,508	A	8/1996	Affinito
5,554,220	A	9/1996	Forrest et al.
5,576,101	A	11/1996	Saitoh et al.
5,607,789	A	3/1997	Treger et al.
5,620,524	A	4/1997	Fan et al.
5,629,389	A	5/1997	Roitman et al.
5,654,084	A	8/1997	Egert
5,681,615	A	10/1997	Affinito et al.
5,681,666	A	10/1997	Treger et al.
5,684,084	A	11/1997	Lewin et al.
5,686,360	A	11/1997	Harvey, III et al.
5,693,956	A	12/1997	Shi et al.
5,711,816	A	1/1998	Kirlin et al.
5,725,909	A	3/1998	Shaw et al.
5,731,661	A	3/1998	So et al.
5,747,182	A	5/1998	Friend et al.
5,757,126	A	5/1998	Harvey, III et al.
5,759,329	A	6/1998	Krause et al.

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

BE	704 297	2/1968
DE	19603746	4/1997
EP	0 299 753	1/1989
EP	0 340 935	11/1989
EP	0 390 540	10/1990
EP	0 547 550	6/1993
EP	0 590 467	4/1994
EP	0 722 787	7/1996
EP	0 787 826	8/1997
EP	0 916 394	5/1999
EP	0 931 850	7/1999
EP	0 977 469	2/2000
JP	63136316	6/1988
JP	64-18441	1/1989
JP	2-183230	7/1990
JP	08325713	12/1996
JP	09059763	3/1997
WO	WO 87 07848	12/1987
WO	WO 95 10117	4/1995
WO	WO 97 04885	2/1997
WO	WO 97 22631	6/1997
WO	WO 98 10116	3/1998
WO	WO 98 18852	5/1998
WO	WO 99 16557	4/1999
WO	WO 99 16931	4/1999

OTHER PUBLICATIONS

Affinito, J.F., et al., "Vacuum Deposition of Polymer Electrolytes On Flexible Substrates", "Proceedings of the Ninth International Conference on Vacuum Web Coating", Nov. 1995 ed R. Bakish, Bakish Press 1995, p. 20–36.

Vossen, J.L. et al., Thin Film Processes, Academic Press, 1978, Part II, Chapter II–1, Glow Discharge Sputter Deposition, p. 12–63; Part IV, Chapter IV–1 Plasma Depositon of Inorganic Compounds and Chapter IV–2 Glow Discharge Polymerization, p. 335–397.

Penning, F.M., Electrical Discharges in Gasses, Gordon and Breach Science Publishers, 1965, Chapters 5–6, p. 19–35, and Chapter 8, p.41–50.

Affinito, J.D., et al., "High Rate Vacuum Deposition of Polymer Electrolytes", Journal Vacuum Science Technology A 14(3), May/Jun. 1996.

Inoue et al., Proc. Jpn. Congr. Mater. Res., vol. 33, p. 177–9, 1990.

(List continued on next page.)

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(57) **ABSTRACT**

A barrier assembly. The barrier assembly includes at least one barrier stack having at least one barrier layer and at least one polymer layer. The barrier stack has an oxygen transmission rate of less than 0.005 cc/m^2/day at 23° C. and 0% relative humidity, and an oxygen transmission rate of less than 0.005 cc/m^2/day at 38° C. and 90% relative humidity. The barrier stack also has a water vapor transmission rate of less than 0.005 g/m^2/day at 38° C. and 100% relative humidity. A method for making a barrier assembly is also disclosed.

25 Claims, 1 Drawing Sheet

BOE-1021
BOE Tech. Grp. Co. v. Samsung Display Co.
IPR2025-01481

U.S. PATENT DOCUMENTS

5,771,562	A		6/1998	Harvey, III et al.
5,792,550	A		8/1998	Phillips et al.
5,811,177	A		9/1998	Shi et al.
5,811,183	A		9/1998	Shaw et al.
5,821,692	A		10/1998	Rogers et al.
5,844,363	A		12/1998	Gu et al.
5,872,355	A		2/1999	Hueschen
5,902,641	A		5/1999	Affinito et al.
5,902,688	A		5/1999	Antoniadis et al.
5,904,958	A		5/1999	Dick et al.
5,912,069	A		6/1999	Yializis et al.
5,922,161	A		7/1999	Wu et al.
5,945,174	A		8/1999	Shaw et al.
5,948,552	A		9/1999	Antoniadis et al.
5,952,778	A		9/1999	Haskal et al.
5,965,907	A		10/1999	Huang et al.
5,996,498	A		12/1999	Lewis
6,045,864	A		4/2000	Lyons et al.
6,083,628	A		7/2000	Yializis
6,146,225	A	*	11/2000	Sheets et al.
6,178,082	B1	*	1/2001	Farooq et al.
6,198,217	B1		3/2001	Suzuki et al.

OTHER PUBLICATIONS

Affinito J D et al., "PML/Oxide/PML Barrier Layer Performance Differences Arising From Use Of UV Or Electron Beam Polymerization of the PML Layers" Thin Solid Films, Elsevier Science S.A., vol. 308–309, Oct. 31, 1997, pp. 19–25.

Notification of Transmittal of the International Search Report Or The Declaration, Mar. 3, 2000, PCT/US99/29853.

Gustafsson, G et al., "Flexible light–emitting diodes made from soluble conducting polymers", Nature, vol. 357, Jun. 11, 1992, pp. 447–449.

Affinito, J D et al., "Polymer–Oxide Transparent Barrier Layers", SVC 39th Annual Technical Conference, Vacuum Web Coating Session, 1996, pp. 392–397.

Affinito, J D et al., "PML/Oxide/PML Barrier Layer Performance Differences Arising From Use of UV Or Electron Beam Polymerization Of The PML Layers", SVC 40th Annual Technical Conference. 1997. pp. 19–25.

* cited by examiner

FIG. 1

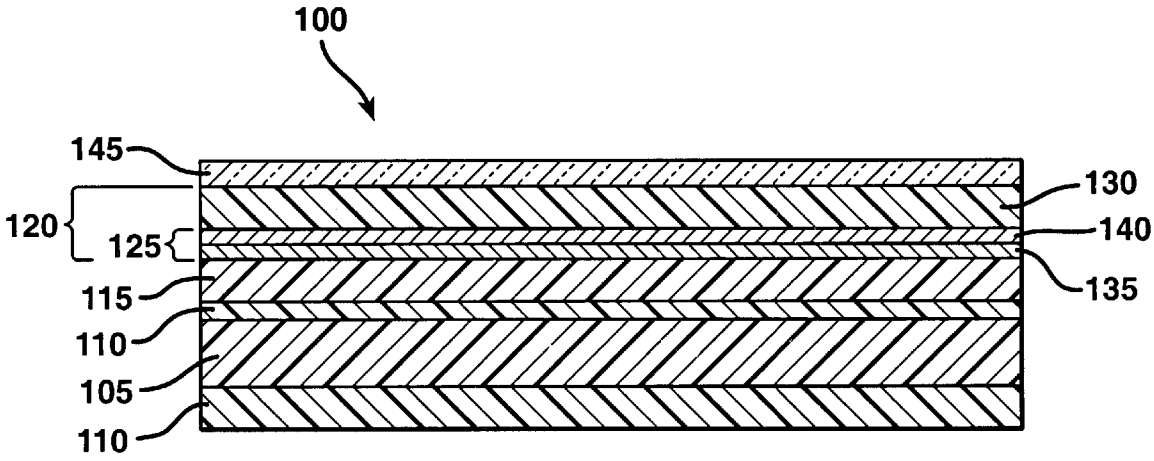
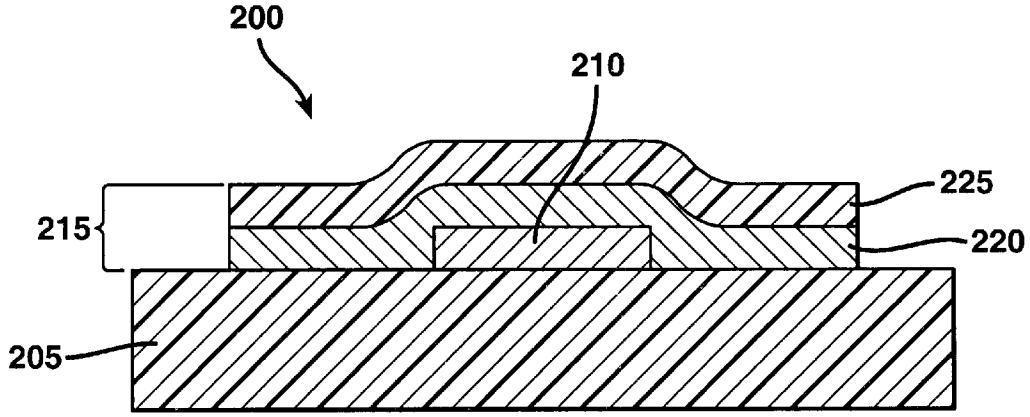

100
145
120
125
115
110
105
110
130
140
135

FIG. 2


200
210
215
205
225
220

ULTRABARRIER SUBSTRATES

BACKGROUND OF THE INVENTION

The present invention relates generally to barrier coatings, and more particularly to barrier coatings having improved barrier properties.

Many different types of products are sensitive to gas and liquids, which can cause deterioration of the product or render it useless, including electronics, medical devices, and pharmaceuticals. Barrier coatings have been included in the packaging for these environmentally sensitive products to protect them from gas and liquid transmission. As used herein, the term environmentally sensitive means products which are subject to degradation caused by permeation of environmental gases or liquids, such as oxygen and water vapor in the atmosphere or chemicals used in the processing, handling, storage, and use of the product.

Plastics are often used in product packaging. However, the gas and liquid permeation resistance of plastics is poor, often several orders of magnitude below what is required for product performance. For example, the oxygen transmission rates for materials such polyethylene terephthalate (PET) are as high as 1550 cc/m^2/day/micron of thickness (or 8.7 cc/m^2/day for 7 mil thickness PET), and the water vapor transmission rates are also in this range. Certain display applications using environmentally sensitive display devices, such as organic light emitting devices, require encapsulation that has a maximum oxygen transmission rate of 10^{-4} to 10^{-2} cc/m^2/day, and a maximum water vapor transmission rate of 10^{-5} to 10^{-6} g/m^2/day.

Barrier coatings have been applied to plastic substrates to decrease their gas and liquid permeability. Barrier coatings typically consist of single layer thin film inorganic materials, such as Al, SiO_X, AlO_x, and Si_3N_4 vacuum deposited on polymeric substrates. A single layer coating on PET reduces oxygen permeability to levels of about 0.1 to 1.0 cc/m^2/day, and water vapor permeability to about 0.1 to 1.0 g/m^2/day, which is insufficient for many display devices.

Barrier coatings which include alternating barrier layers and polymeric layers have been developed. For example, U.S. Pat. Nos. 5,607,789 and 5,681,666 disclose a moisture barrier for an electrochemical cell tester. However, the claimed moisture barrier ranges from 2 to 15 micrograms/in^2/day which corresponds to a rate of 0.003 to 0.023 g/m^2/day. U.S. Pat. No. 5,725,909 to Shaw et al. discloses a coating for packaging materials which has an acrylate layer and an oxygen barrier layer. The oxygen transmission rate for the coating was reported to be 0.1 cc/m^2/day at 23° C. and the water vapor transmission rate was reported to be 0.01 g/m^2/day in D. G. Shaw and M. G. Langlois, Society of Vacuum Coaters, 37th Annual Technical Conference Proceedings, p. 240–244, 1994. The oxygen transmission rates for these coatings are inadequate for many display devices.

Thus, there is a need for an improved, lightweight, barrier coating, and for methods for making such a barrier coating.

SUMMARY OF THE INVENTION

The present invention meets these needs by providing a barrier assembly and a method for making such an assembly. The barrier assembly includes at least one barrier stack having at least one barrier layer and at least one polymer layer. The barrier stack has an oxygen transmission rate of less than 0.005 cc/m^2/day at 23° C. and 0% relative humidity, and an oxygen transmission rate of less than 0.005 cc/m^2/day at 38° C. and 90% relative humidity. It also preferably has a water vapor transmission rate of less than 0.005 g/m$^{2/}$day at 38° C. and 100% relative humidity.

Preferably, the barrier layers of the barrier stacks are substantially transparent. At least one of the barrier layers preferably comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.

The barrier layers can be substantially opaque, if desired. The opaque barrier layers are preferably selected from opaque metals, opaque polymers, and opaque ceramics.

The barrier assembly can include a substrate adjacent to the at least one barrier stack. By adjacent, we mean next to, but not necessarily directly next to. There can be additional layers intervening between the adjacent layers. The substrate can either be flexible or rigid. It is preferably made of a flexible substrate material, such as polymers, metals, paper, fabric, and combinations thereof. If a rigid substrate is used, it is preferably a ceramic (including glasses), a metal, or a semiconductor.

The polymer layers of the barrier stacks are preferably acrylate-containing polymers. As used herein, the term acrylate-containing polymers includes acrylate-containing polymers, methacrylate-containing polymers, and combinations thereof The polymer layers can be the same or different.

The barrier assembly can include additional layers if desired, such as polymer smoothing layers, scratch resistant layers, antireflective coatings, or other functional layers.

The present invention also involves a method of making the barrier assembly. The method includes providing a substrate, and placing at least one barrier stack on the substrate. The barrier stack includes at least one barrier layer and at least one polymer layer.

The at least one barrier stack can be placed on the substrate by deposition, preferably vacuum deposition, or by laminating the barrier stack over the environmentally sensitive device. The lamination can be performed using an adhesive, solder, ultrasonic welding, pressure, or heat.

Accordingly, it is an object of the present invention to provide a barrier assembly, and to provide a method of making such a barrier assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-section of one embodiment of the barrier assembly of the present invention.

FIG. **2** is a cross-section of an encapsulated device made using the barrier assembly of the present invention.

DESCRIPTION OF THE INVENTION

One embodiment of the barrier assembly of the present invention is shown in FIG. **1**. The barrier assembly is supported by a substrate **105**. The substrate **105** can be either rigid or flexible. A flexible substrate can be any flexible material, including, but not limited to: polymers, for example, polyethylene terephthalate (PET), polyethylene naphthalate (PEN), or high temperature polymers, such as polyether sulfone (PES), polyimides, or Transphan™ (a high glass transition temperature cyclic olefin polymer available from Lofo High Tech Film, GMBH of Weil am Rhein, Germany); metal; paper; fabric; and combinations thereof. Rigid substrates are preferably glass, metal, or silicon.

There are scratch resistant layers **110** on either side of the substrate **105** to protect it. When a scratch resistant layer is

included, it is preferred that both sides of the substrate have a scratch resistant layer. This helps to balance stresses and prevent deformation of a flexible substrate during processing and use.

On top of the scratch resistant layer **110**, there is a polymer smoothing layer **115**. The polymer smoothing layer decreases surface roughness, and encapsulates surface defects, such as pits, scratches, and digs. This produces a planarized surface which is ideal for subsequent deposition of layers. Depending on the desired application, there can be additional layers deposited on the substrate **105**, such as organic or inorganic layers, planarizing layers, electrode layers, antireflective coatings, and other functional layers. In this way, the substrate can be specifically tailored to different applications.

The first barrier stack **120** is adjacent to the polymer smoothing layer **115**. The first barrier stack **120** includes a barrier layer **125** and a polymer layer **130**. The first barrier layer **125** includes barrier layers **135** and **140**. Barrier layers **135** and **140** can be made of the same barrier material or of different barrier materials.

Although FIG. **1** shows a barrier stack with two barrier layers and one polymer layer, the barrier stacks can have one or more polymer layers and one or more barrier layers. There could be one polymer layer and one barrier layer, there could be one or more polymer layers on one side of one or more barrier layers, or there could be one or more polymer layers on both sides of one or more barrier layers. The important feature is that the barrier stack have at least one polymer layer and at least one barrier layer. The barrier layers and polymer layers in the barrier stack can be made of the same material or of a different material. The barrier layers are typically about 100–400 Å thick, and the polymer layers are typically about 1000–10,000 Å thick.

Although only one barrier stack is shown in FIG. **1**, the number of barrier stacks is not limited. The number of barrier stacks needed depends on the substrate material used and the level of permeation resistance needed for the particular application. One or two barrier stacks should provide sufficient barrier properties for some applications. The most stringent applications may require five or more barrier stacks.

There is a transparent conductor **145**, such as an indium tin oxide layer, adjacent to the first barrier stack **120**. There can be additional overcoat layers on top of the barrier stack, such as organic or inorganic layers, planarizing layers, transparent conductors, antireflective coatings, or other functional layers, if desired. This allows the barrier assembly to be tailored to the application.

FIG. **2** shows a barrier assembly being used to encapsulate an environmentally sensitive display device. The substrate **205** has an environmentally sensitive display device **210** on it. There is a barrier stack **215** over the environmentally sensitive display device **210** encapsulating it. The barrier stack **215** includes a barrier layer **220** and a polymer layer **225**.

The environmentally sensitive display device **210** can be any display device which is environmentally sensitive. Examples of environmentally sensitive display devices include, but are not limited to liquid crystal displays (LCDs), light emitting diodes (LEDs), light emitting polymers (LEPs), electronic signage using electrophoretic inks, electroluminescent devices (EDs), and phosphorescent devices. These display devices can be made using known techniques, such as those described in U.S. Pat. Nos. 6,025,899, 5,995,191, 5,994,174, 5,956,112 (LCDs); U.S. Pat. Nos. 6,005,692, 5,821,688, 5,747,928 (LEDs); U.S. Pat. Nos. 5,969,711, 5,961,804, 4,026,713 (E Ink); U.S. Pat. Nos. 6,023,373, 6,023,124, 6,023,125 (LEPs); and U.S. Pat. Nos. 6,023,073, 6,040,812, 6,019,654, 6,018,237, 6,014,119, 6,010,796 (EDs), which are incorporated herein by reference.

The method of making the barrier assembly will be described with reference to FIGS. **1** and **2**. Any initial layers which are desired, such as scratch resistant layers, planarizing layers, electrically conductive layers, etc., can be coated, deposited, or otherwise placed on the substrate. A polymer smoothing layer is preferably included to provide a smooth base for the remaining layers. It can be formed by depositing a layer of polymer, for example, an acrylate-containing polymer, onto the substrate or previous layer. The polymer layer can be deposited in vacuum or by using atmospheric processes such as spin coating and/or spraying. Preferably, an acrylate-containing monomer, oligomer, or resin is deposited and then polymerized in situ to form the polymer layer. As used herein, the term acrylate-containing monomer, oligomer, or resin includes acrylate-containing monomers, oligomers, and resins, methacrylate-containing monomers, oligomers, and resins, and combinations thereof.

The barrier stack is then placed on the substrate. The barrier stack includes at least one barrier layer and at least one polymer layer. The barrier stacks are preferably made by vacuum deposition. The barrier layer can be vacuum deposited onto the polymer smoothing layer, the substrate, or the previous layer. The polymer layer is then deposited on the barrier layer, preferably by flash evaporating acrylate-containing monomers, oligomers, or resins, condensing on the barrier layer, and polymerizing in situ in a vacuum chamber. U.S. Pat. Nos. 5,440,446 and 5,725,909, which are incorporated herein by reference, describe methods of depositing thin film, barrier stacks.

Vacuum deposition includes flash evaporation of acrylate-containing monomer, oligomer, or resin with in situ polymerization under vacuum, plasma deposition and polymerization of acrylate-containing monomer, oligomer, or resin, as well as vacuum deposition of the barrier layers by sputtering, chemical vapor deposition, plasma enhanced chemical vapor deposition, evaporation, sublimation, electron cyclotron resonance-plasma enhanced vapor deposition (ECR-PECVD), and combinations thereof.

In order to protect the integrity of the barrier layer, the formation of defects and/or microcracks in the deposited layer subsequent to deposition and prior to downstream processing should be avoided. The barrier assembly is preferably manufactured so that the barrier layers are not directly contacted by any equipment, such as rollers in a web coating system, to avoid defects that may be caused by abrasion over a roll or roller. This can be accomplished by designing the deposition system such that the barrier layers are always covered by polymer layers prior to contacting or touching any handling equipment.

When the barrier stack is being used to encapsulate an environmentally sensitive display device, the substrate can be prepared as described above, and the environmentally sensitive display device placed on the substrate. Alternatively, the environmentally sensitive display device can be placed directly on a substrate (or on a substrate with functional layers, such as planarizing layers, scratch resistant layers, etc.).

The environmentally sensitive display device can be placed on the substrate by deposition, such as vacuum deposition. Alternatively it can be placed on the substrate by lamination. The lamination can use an adhesive, glue, or the

like, or heat to seal the environmentally sensitive display device to the substrate.

A barrier stack is then placed over the environmentally sensitive display device to encapsulate it. The second barrier stack can be placed over the environmentally sensitive display device by deposition or lamination.

The barrier layers in the first and second barrier stacks may be any barrier material. The barrier layers in the first and second barrier stacks can be made of the same material or a different material. In addition, multiple barrier layers of the same or different barrier materials can be used in a barrier stack.

The barrier layers can be transparent or opaque, depending on the design of the packaging, and application for which it is to be used. Preferred transparent barrier materials include, but are not limited to, metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof. The metal oxides are preferably selected from silicon oxide, aluminum oxide, titanium oxide, indium oxide, tin oxide, indium tin oxide, tantalum oxide, zirconium oxide, niobium oxide, and combinations thereof. The metal nitrides are preferably selected from aluminum nitride, silicon nitride, boron nitride, and combinations thereof. The metal oxynitrides are preferably selected from aluminum oxynitride, silicon oxynitride, boron oxynitride, and combinations thereof.

Opaque barrier layers can be also be used in some barrier stacks. Opaque barrier materials include, but are not limited to, metals, ceramics, polymers, and cermets. Examples of opaque cermets include, but are not limited to, zirconium nitride, titanium nitride, hafnium nitride, tantalum nitride, niobium nitride, tungsten disilicide, titanium diboride, and zirconium diboride.

The polymer layers of the first and second barrier stacks are preferably acrylate-containing monomers, oligomers, or resins. The polymer layers in the first and second barrier stacks can be the same or different. In addition, the polymer layers within each barrier stack can be the same or different.

In a preferred embodiment, the barrier stack includes a polymer layer and two barrier layers. The two barrier layers can be made from the same barrier material or from different barrier materials. The thickness of each barrier layer in this embodiment is about one half the thickness of the single barrier layer, or about 50 to 200 Å. There are no limitations on the thickness, however.

When the barrier layers are made of the same material, they can be deposited either by sequential deposition using two sources or by the same source using two passes. If two deposition sources are used, deposition conditions can be different for each source, leading to differences in microstructure and defect dimensions. Any type of deposition source can be used. Different types of deposition processes, such as magnetron sputtering and electron beam evaporation, can be used to deposit the two barrier layers.

The microstructures of the two barrier layers are mismatched as a result of the differing deposition sources/parameters. The barrier layers can even have different crystal structure. For example, Al_2O_3 can exist in different phases (alpha, gamma) with different crystal orientations. The mismatched microstructure can help decouple defects in the adjacent barrier layers, enhancing the tortuous path for gases and water vapor permeation.

When the barrier layers are made of different materials, two deposition sources are needed. This can be accomplished by a variety of techniques. For example, if the materials are deposited by sputtering, sputtering targets of different compositions could be used to obtain thin films of different compositions. Alternatively, two sputtering targets of the same composition could be used but with different reactive gases. Two different types of deposition sources could also be used. In this arrangement, the lattices of the two layers are even more mismatched by the different microstructures and lattice parameters of the two materials.

A single pass, roll-to-roll, vacuum deposition of a three layer combination on a PET substrate, i.e., PET substrate/polymer layer/barrier layer/polymer layer, can be more than five orders of magnitude less permeable to oxygen and water vapor than a single oxide layer on PET alone. See J. D. Afinito, M. E. Gross, C. A. Coronado, G. L. Graff, E. N. Greenwell, and P. M. Martin, *Polymer-Oxide Transparent Barrier Layers Produced Using PML Process*, 39th Annual Technical Conference Proceedings of the Society of Vacuum Coaters, Vacuum Web Coating Session, 1996, pages 392–397; J. D. Affinito, S. Eufinger, M. E. Gross, G. L. Graff, and P. M. Martin, *PML/Oxide/PML Barrier Layer Performance Differences Arising From Use of UV or Electron Beam Polymerization of the PML Layers*, Thin Solid Films, Vol. 308, 1997, pages 19–25. This is in spite of the fact that the effect on the permeation rate of the polymer multilayers (PML) layers alone, without the barrier layer (oxide, metal, nitride, oxynitride) layer, is barely measurable. It is believed that the improvement in barrier properties is due to two factors. First, permeation rates in the roll-to-roll coated oxide-only layers were found to be conductance limited by defects in the oxide layer that arose during deposition and when the coated substrate was wound up over system idlers/rollers. Asperities (high points) in the underlying substrate are replicated in the deposited inorganic barrier layer. These features are subject to mechanical damage during web handling/take-up, and can lead to the formation of defects in the deposited film. These defects seriously limit the ultimate barrier performance of the films. In the single pass, polymer/barrier/polymer process, the first acrylic layer planarizes the substrate and provides an ideal surface for subsequent deposition of the inorganic barrier thin film. The second polymer layer provides a robust "protective" film that minimizes damage to the barrier layer and also planarizes the structure for subsequent barrier layer (or environmentally sensitive display device) deposition. The intermediate polymer layers also decouple defects that exist in adjacent inorganic barrier layers, thus creating a tortuous path for gas diffision.

The permeability of the barrier stacks used in the present invention is shown in Table 1. The barrier stacks of the present invention on polymeric substrates, such as PET, have measured oxygen transmission rate (OTR) and water vapor transmission rate (WVTR) values well below the detection limits of current industrial instrumentation used for permeation measurements (Mocon OxTran 2/20L and Permatran). Table 1 shows the OTR and WVTR values (measured according to ASTM F 1927-98 and ASTM F 1249-90, respectively) measured at Mocon (Minneapolis, Minn.) for several barrier stacks on 7 mil PET, along with reported values for other materials.

TABLE 1

	Oxygen Permeation Rate (cc/m^2/day)		Water Vapor Permeation (g/m^2/day)$^+$	
Sample	23° C.	38° C.	23° C.	38° C.
Native 7 mil PET	7.62	—	—	—
1-barrier stack	<0.005	<0.005*	—	0.46$^+$

TABLE 1-continued

Sample	Oxygen Permeation Rate ($cc/m^2/day$) 23° C.	38° C.	Water Vapor Permeation ($g/m^2/day$)+ 23° C.	38° C.
1-barrier stack with ITO	<0.005	<0.005*	—	0.011+
2-barrier stacks	<0.005	<0.005*	—	<0.005+
2-barrier stacks with ITO	<0.005	<0.005*	—	<0.005+
5-barrier stacks	<0.005	<0.005*	—	<0.005+
5-barrier stacks with ITO	<0.005	<0.005*	—	<0.005+
DuPont film[1] (PET/Si_3N_4 or PEN/Si_3N_4)	0.3	—	—	—
Polaroid[3]	<1.0	—	—	—
PET/Al[2]	0.6	—	0.17	—
PET/silicon oxide[2]	0.7–1.5	—	0.15–0.9	—
Teijin LCD film (HA grade - TN/STN)[3]	<2	—	<5	—

*38° C., 90% RH, 100% O_2
+38° C., 100% RH
[1]P. F. Carcia, 46th International Symposium of the American Vacuum Society, Oct. 1999
[2]Langowski, H. C., 39th Annual Technical Conference Proceedings, SVC, pp. 398–401 (1996)
[3]Technical Data Sheet

As the data in Table 1 shows, the barrier stacks of the present invention provide oxygen and water vapor permeation rates several orders of magnitude better than PET coated with aluminum, silicon oxide, or aluminum oxide. Typical oxygen permeation rates for other barrier coatings range from about 1 to about 0.1 $cc/m^2/day$. The oxygen transmission rate for the barrier stacks of the present invention is less than 0.005 $cc/m^2/day$ at 23° C. and 0% relative humidity, and at 38° C. and 90% relative humidity. The water vapor transmission rate is less than 0.005 $g/m^2/day$ at 38° C. and 100% relative humidity. The actual transmission rates are lower, but cannot be measured with existing equipment.

The barrier assemblies were also tested by encapsulating organic light emitting devices using the barrier stacks of the present invention. The organic light emitting devices are extremely sensitive to water vapor, and they are completely destroyed in the presence of micromole quantities of water vapor. Experimentation and calculations suggest that the water vapor transmission rate through the encapsulation film must be on the order of about 10^{-6} to 10^{-5} $g/m^2/day$ to provide sufficient barrier protection for acceptable device lifetimes. The experiments/calculations are based on the detrimental hydrolysis reaction of water vapor with the extremely thin (less than 10 nm), low work function, cathode materials (Ca, Mg, Li, LiF). Hydrolysis of the cathode leads to the formation of non-conductive reaction products (such as hydroxides and oxides) that delaminate or blister away from the electron transport layers of the organic light emitting devices, resulting in the formation of dark spots on the device.

The organic light emitting devices encapsulated in the barrier stacks of the present invention have been in operation for over six months without measurable degradation. The extrapolated lifetime for the encapsulated devices exceeds the required 10,000 hours necessary to satisfy industry standards. The barrier stacks are extremely effective in preventing oxygen and water penetration to the underlying components, substantially outperforming other thin-film barrier coatings on the market.

The preferred deposition process is compatible with a wide variety of substrates. Because the preferred process involves flash evaporation of a monomer and magnetron sputtering, deposition temperatures are well below 100° C., and stresses in the coating can be minimized. Multilayer coatings can be deposited at high deposition rates. No harsh gases or chemicals are used, and the process can be scaled up to large substrates and wide webs. The barrier properties of the coating can be tailored to the application by controlling the number of layers, the materials, and the layer design. Thus, the present invention provides a barrier stack with the exceptional barrier properties necessary for hermetic sealing of an environmentally sensitive display device, or other environmentally sensitive device. It permits the production of an encapsulated environmentally sensitive display device.

While certain representative embodiments and details have been shown for purposes of illustrating the invention, it will be apparent to those skilled in the art that various changes in the compositions and methods disclosed herein may be made without departing from the scope of the invention, which is defined in the appended claims.

What is claimed is:

1. A barrier assembly comprising:

at least one barrier stack comprising at least one barrier layer and at least one polymer layer, wherein the at least one barrier stack has an oxygen transmission rate of less than 0.005 $cc/m^2/day$ at 23° C. and 0% relative humidity.

2. The barrier assembly of claim **1** wherein the at least one barrier stack has an oxygen transmission rate of less than 0.005 $cc/m^2/day$ at 38° C. and 90% relative humidity.

3. The barrier assembly of claim **1** wherein the at least one barrier stack has a water vapor transmission rate of less than 0.005 $g/m^2/day$ at 38° C. and 100% relative humidity.

4. The barrier assembly of claim **1** further comprising a substrate adjacent to the at least one barrier stack.

5. The barrier assembly of claim **1** wherein the at least one barrier layer is substantially transparent.

6. The barrier assembly of claim **1** wherein at least one of the at least one barrier layer comprises a material selected from metal oxides, metal nitrides, metal carbides, metal oxynitrides, metal oxyborides, and combinations thereof.

7. The barrier assembly of claim **6** wherein the metal oxides are selected from silicon oxide, aluminum oxide, titanium oxide, indium oxide, tin oxide, indium tin oxide, tantalum oxide, zirconium oxide, niobium oxide, and combinations thereof.

8. The barrier assembly of claim **6** wherein the metal nitrides are selected from aluminum nitride, silicon nitride, boron nitride, and combinations thereof.

9. The barrier assembly of claim **6** wherein the metal oxynitrides are selected from aluminum oxynitride, silicon oxynitride, boron oxynitride, and combinations thereof.

10. The barrier assembly of claim **1** wherein the at least one barrier layer is substantially opaque.

11. The barrier assembly of claim **1** wherein at least one of the at least one barrier layers is selected from opaque metals, opaque polymers, opaque ceramics, and opaque cermets.

12. The barrier assembly of claim **4** wherein the substrate comprises a flexible substrate material.

13. The barrier assembly of claim **12** wherein the flexible substrate material is selected from polymers, metals, paper, fabric, and combinations thereof.

14. The barrier assembly of claim **4** wherein the substrate comprises a rigid substrate material.

15. The barrier assembly of claim 14 wherein the rigid substrate material is selected from ceramics, metals, and semiconductors.

16. The barrier assembly of claim 1 wherein at least one of the at least one polymer layers comprises an acrylate-containing polymer.

17. The barrier assembly of claim 4 further comprising a polymer smoothing layer adjacent to the substrate.

18. The barrier assembly of claim 4 further comprising a scratch resistant layer adjacent to the substrate.

19. The barrier assembly of claim 4 further comprising an anti-reflective coating adjacent to the substrate.

20. The barrier assembly of claim 4 further comprising an anti-fingerprint coating adjacent to the substrate.

21. The barrier assembly of claim 4 further comprising an anti-static coating adjacent to the substrate.

22. The barrier assembly of claim 1 wherein the at least one barrier layer comprises two barrier layers.

23. The barrier assembly of claim 22 wherein the two barrier layers are made of the same barrier material.

24. The barrier assembly of claim 22 wherein the two barrier layers are made of different barrier materials.

25. The barrier assembly of claim 11 wherein at least one of the at least one barrier layers is opaque cermet selected from zirconium nitride, titanium nitride, hafnium nitride, tantalum nitride, niobium nitride, tungsten disilicide, titanium diboride, and zirconium diboride.

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